Digital Technology Adoption as a Catalyst for Green Digital Transformation: The Mediating Role of Digital Innovation Capability in Malaysian E&E Manufacturing

Hanis Ab Hannan[1], Aida Syuhada Abdul Halim[2], Nurhanan Syafiah Abdul Razak[*3]

[1,2,3]UniKL Business School, Universiti Kuala Lumpur, Kuala Lumpur, Malaysia

[*]Corresponding Author

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ABSTRACT

This conceptual paper develops a framework explaining how Digital Technology Adoption may facilitate Green Digital Transformation in Malaysia's electrical and electronics (E&E) manufacturing industry through Digital Innovation Capability. Digital Technology Adoption is conceptualised through four dimensions: Technology Infrastructure, Digital Integration, Data Analytics Capability, and Technology Utilization. Drawing on the Resource-Based View and Dynamic Capabilities Theory, the paper argues that digital resources alone are insufficient to generate environmentally oriented transformation unless firms can convert those resources into innovation capability. Digital Innovation Capability is therefore positioned as the mediating mechanism through which technology adoption can support green transformation. The proposed framework addresses gaps concerning the mechanisms connecting digital technology with green outcomes, the multidimensional nature of technology adoption, and the limited context-specific literature on Malaysian E&E manufacturing. Propositions are developed for future empirical validation, with implications for manufacturing strategy, digital capability development, and sustainability-oriented transformation.

Keywords: Digital Technology Adoption; Digital Innovation Capability; Green Digital Transformation; E&E Manufacturing; Malaysia; Resource-Based View; Dynamic Capabilities Theory

INTRODUCTION

Digital technologies are revolutionizing manufacturing by enhancing resource management, production processes, decision-making and environmental impacts. This has added impetus to 'Green Digital Transformation (GDT)' in which digital technologies are applied to achieve business and environmental objectives. The independent variable of this conceptual paper is Digital Technology Adoption (DTA) which is comprised of four components: Technology Infrastructure (TI), Digital Integration (DI), Data Analytics Capability (DAC) and Technology Utilization (TU). Digital Innovation Capability (DIC) is suggested as a mediating variable due to the need for an organization to use digital technologies to create and execute innovation. The study is conducted in the Electrical and Electronics (E&E) manufacturing sector in Malaysia which is at the early stage of embracing Industry 4.0 technologies, but currently confronts issues like skills shortage, technology benefit uncertainty, and limited funding (OECD, 2024; Chen & Wang, 2024; Liu et al., 2023; Yeap et al., 2024). Three research gaps are identified. First of all, the mechanism between the adoption of digital technology and green outcomes has not been fully understood, as previous studies have demonstrated that digital transformation can contribute to green innovation and sustainability. Thus, it is of interest to investigate in this conceptual paper whether DIC is a mediator between DTA and GDT. Second, the existing studies tend to adopt an organizational perspective to measure digital transformation, and the relationships between the dimensions of digital technology and innovation capability are not clearly identified. This conceptual paper, therefore, looks at DTA in terms of TI, DI, DAC and TU in isolation. Third, most of the current studies have been conducted in manufacturing companies in China and the evidence in Malaysia and Southeast Asia is limited. This conceptual paper therefore provides context specific evidence in E&E

manufacturing industry in Malaysia (Wang et al., 2024; Chen & Wang, 2024; Liu et al., 2023; Yeap et al., 2024). Keeping these gaps in mind, this conceptual paper explores the relationships between DTA, DIC and GDT, namely the contribution of TI, DI, DAC and TU to DIC and the contribution of DIC to GDT. The study is underpinned by the Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT) which underpin the importance of the organizational resources, capabilities and capacity to adapt to changes. This conceptual paper seeks to gain a deeper insight into the utilization of digital resources and innovation potential of E&E manufacturing firms in Malaysia to facilitate green transformation.

LITERATURE REVIEW

This chapter reviews the literature on the selected industry and research variables: Digital Technology Adoption as the independent variable, Digital Innovation Capability as the mediator and Green Digital Transformation as the dependent variable. It discusses the E&E manufacturing industry, Green Digital Transformation, Digital Technology Adoption and its four dimensions: Technology Infrastructure, Digital Integration, Data Analytics Capability and Technology Utilization. The chapter also discusses Digital Innovation Capability, the underpinning theories of Dynamic Capabilities Theory and Resource-Based View and concludes with the research framework and nine propositions.

Electrical and Electronics (E&E) Manufacturing Industry

The Electrical and Electronics (E&E) manufacturing industry is an important contributor to Malaysia's manufacturing sector and relies heavily on technology, automation, data, and innovation. Globally, manufacturers are increasingly adopting Industry 4.0 technologies to improve production efficiency, flexibility, quality, and competitiveness (Shen et al., 2022; Wang et al., 2022). However, adoption can be constrained by technological, financial, and human resource challenges. In Malaysia, the E&E industry is particularly relevant due to its role in global E&E and semiconductor supply chains. Malaysian manufacturers adopt Industry 4.0 mainly to improve production efficiency and reduce costs while skills shortages, limited funding and uncertainty regarding technological investments remain key barriers (Yeap et al., 2024; Newaz et al., 2025). Previous research also indicates that Industry 4.0 implementation can improve sustainable performance, including environmental outcomes, among Malaysian manufacturers (Baiga & Yadegaridehkordi, 2023).

Green Digital Transformation

Green Digital Transformation (GDT) refers to the use of digital technologies and capabilities to transform organizational processes while simultaneously improving environmental sustainability. In manufacturing, GDT can support more efficient production, resource optimization, waste reduction, environmental monitoring, and data-driven decision-making.

Globally, technologies such as AI, IoT, big data analytics, cloud computing and automation are increasingly used to improve operational and environmental performance (Xu et al., 2023; Zhang et al., 2023). Digital transformation can also support green development through green products, technological innovation, and green investment (Chen et al., 2023).

In Malaysia, GDT is increasingly relevant as manufacturing moves towards Industry 4.0 and smart manufacturing. Baiga and Yadegaridehkordi (2023) found that Industry 4.0 implementation was associated with environmental and financial sustainable performance among 269 Malaysian manufacturing firms. Therefore, this conceptual paper views GDT as the use of digital technologies to transform E&E manufacturing operations while improving environmental sustainability.

Digital Technology Adoption

For future empirical validation, DTA is provisionally specified as a formative higher-order composite: the four distinct dimensions jointly define the breadth and maturity of operational adoption, and removing one changes the meaning of the composite. Each first-order dimension should be measured with content-appropriate

indicators and evaluated separately; the higher-order composite should be assessed for collinearity, indicator weights, and convergent validity using an appropriate global criterion. This is a proposed measurement specification, not an empirically validated result. As the nine propositions concern the individual dimensions, future researchers may estimate the four dimension-to-mediator paths directly and use the higher-order composite as a complementary robustness specification, avoiding simultaneous redundant paths.

Construct specification and dimensional logic. Digital Technology Adoption (DTA) is defined here as the extent to which a manufacturing firm has established and operationally embedded digital technologies across its production and management activities. The four dimensions are not interchangeable manifestations of one underlying trait. Technology Infrastructure captures the availability and adequacy of digital assets; Digital Integration captures interconnection across processes and systems; Data Analytics Capability captures the ability to convert data into operational insight; and Technology Utilization captures routine application in work processes. The first two primarily describe enabling resource conditions, whereas the latter two describe enacted organisational capabilities and practices. Their combination is therefore an explicitly multidimensional adoption configuration, rather than a claim that all four dimensions are conceptually identical and effectively use digital technologies in their business and production processes (Shen et al., 2022; Wang et al., 2022). Globally, technologies such as automation, IoT, cloud computing, and data analytics support Industry 4.0 by improving connectivity, monitoring, and decision-making. However, effective adoption requires the capability to integrate and utilize these technologies.

This conceptual paper measures DTA through four dimensions: Technology Infrastructure, Digital Integration, Data Analytics Capability and Technology Utilization. In Malaysia's E&E industry, adoption is mainly driven by the need to improve efficiency and reduce costs while skills shortages, limited funding, and uncertain investment benefits remain barriers (Yeap et al., 2024; Newaz et al., 2025). Effective DTA can therefore support the development of DIC and GDT, as Industry 4.0 adoption is associated with sustainable performance (Baiga & Yadegaridehkordi, 2023).

Technology Infrastructure

This Technology Infrastructure refers to the technological foundation that enables organizations to adopt and utilize digital technologies, including hardware, software, communication networks, computing systems, and data storage. Adequate infrastructure is essential for technologies such as IoT, cloud computing, AI, and automation to collect, process, and exchange information effectively (Shen et al., 2022; Wang et al., 2022).

Globally, technology infrastructure supports the transition from conventional to connected and smart manufacturing by enabling machines, sensors and digital systems to communicate and share production data (Jia et al., 2023). For example, sensors can collect information on machine conditions, while network and computing infrastructure enables the data to be stored and analysed.

In Malaysia, infrastructure is increasingly important as E&E manufacturers adopt Industry 4.0 technologies to improve efficiency and reduce costs. However, limited financial resources and shortages of skilled personnel remain key barriers (Yeap et al., 2024). Therefore, strong Technology Infrastructure provides the foundation for developing Digital Innovation Capability by enabling firms to connect technologies, access data, and support technology-based experimentation.

Digital Integration

Digital Integration refers to the extent to which digital technologies, information systems, organizational processes, and production activities are interconnected and able to exchange data. Unlike simple technology adoption, integration allows information to flow across systems and departments, reducing fragmented information and improving coordination (Shen et al., 2022; Wang et al., 2022).

Globally, digital integration is important for smart manufacturing as firms connect production equipment with enterprise, inventory, quality control, and supply chain systems (Xi et al., 2024). This allows production information to be shared more efficiently, helping firms identify operational problems and respond quickly.

In Malaysia's E&E industry, integrating different Industry 4.0 technologies can help firms maximize the benefits of their existing digital systems despite challenges related to technology, finance, and skills (Yeap et al., 2024). Therefore, Digital Integration can strengthen Digital Innovation Capability by providing employees with broader and more connected information for problem-solving, experimentation, and process improvement.

Data Analytics Capability

The Data Analytics Capability refers to an organization's ability to collect, manage, analyse, and interpret data

to support decision-making and organizational improvements (Bhatti et al., 2022). Manufacturing firms generate large amounts of data from machinery, sensors, quality control, inventory, and supply chain activities.

However, collecting data alone does not create value; firms require appropriate technologies, skills, and resources to transform data into useful information and knowledge. Globally, data analytics enables manufacturers to identify inefficiencies, monitor equipment, improve product quality, and support innovation. For example, analysing machine performance data can help firms identify patterns that indicate possible equipment failure and allow preventive action. Tan et al. (2022), in a study of 402 manufacturing firms, found that Data Analytics Capability positively influenced servitization, demonstrating its role in creating new sources of value.

In Malaysia, Chong et al. (2023) found that Big Data Analytics Capability positively affected competitive advantage and performance among 191 manufacturing firms. Therefore, Data Analytics Capability can contribute to Digital Innovation Capability by helping firms identify patterns, solve problems, and generate insights that support new products, processes, and organizational solutions.

Technology Utilization

Technology Utilization refers to the extent to which firms effectively apply adopted digital technologies in their business and production activities, such as production, quality control, maintenance, planning, and decision-making (Bhatti et al., 2022). Unlike adoption, utilization focuses on how effectively firms and employees gain value from these technologies.

Globally, manufacturers use AI, IoT, robotics, cloud computing, automation, and data analytics to improve processes and solve operational problems. Effective utilization also enables employees to develop practical knowledge and identify new applications, supporting digital capabilities and transformation performance (Shen et al., 2022).

In Malaysia's E&E industry, effective technology utilization can improve production efficiency and reduce costs, although skills shortages remain a key challenge (Yeap et al., 2024; Newaz et al., 2025). Therefore, Technology Utilization is expected to positively influence DIC by enabling employees to apply technologies, identify problems, experiment with solutions, and develop innovative practices.

Digital Innovation Capability

Boundary between adoption and innovation. Digital Innovation Capability (DIC) is distinct from DTA because it concerns the organisational ability to generate, develop, experiment with, and implement novel digital-enabled products, processes, or organisational practices. In contrast, DTA concerns whether and how technologies are provisioned, connected, analysed, and routinely used. An E&E manufacturer may operate sophisticated connected equipment without having systematic processes for digital experimentation or innovation implementation. To minimise construct overlap, indicators of DIC should measure innovation routines and realised capacity for novelty, not mere technology possession or frequency of system use. Likewise, Green Digital Transformation (GDT) should capture environmentally directed transformation of operations and processes, not simply the installation of digital tools or innovation capability itself.

Digital Innovation Capability (DIC) refers to an organization's ability to use digital technologies, knowledge, data, and resources to develop and implement new or improved products, processes, and practices (Wang et al., 2022). Unlike technology adoption, DIC focuses on transforming digital resources into innovation and value, requiring firms to effectively integrate and utilize digital technologies (Shen et al., 2022).

Globally, digital innovation supports manufacturing efficiency, market responsiveness, and sustainability. Digital transformation and capabilities can promote eco-process, eco-product and eco-management innovation, while digitalization can support green transformation through green innovation capabilities (Xu et al., 2023; Wang & He, 2026).

In Malaysia, Digital Innovation Capability is increasingly relevant as E&E manufacturers adopt Industry 4.0

despite challenges in skills, financing, and technology upgrading (Yeap et al., 2024). Therefore, Digital Innovation Capability can help firms convert digital technologies into innovations that improve efficiency, resource utilization, and environmental performance. It is consequently expected to mediate the relationship between Digital Technology Adoption and Green Digital Transformation.

Underpinning Theories

The theories serve complementary explanatory roles. RBV explains the strategic significance of valuable technology infrastructure, connected systems, analytical knowledge and organisational usage routines as heterogeneous firm resources. DCT explains why resource possession does not necessarily yield environmental transformation: firms must sense inefficiencies and environmental opportunities, seize them through experimentation and innovation investment, and transform operating routines. DIC represents the reconfiguration mechanism that bridges adoption conditions and green outcomes. This integration also identifies a boundary condition: when environmental priorities are absent, digital innovation may increase efficiency without producing meaningful green transformation.

Dynamic Capabilities Theory

Dynamic Capabilities Theory (DCT), developed by Teece et al. (1997), explains how organizations maintain competitiveness by integrating, developing, and reconfiguring their resources and capabilities in response to changing environments. Teece (2007) further explains dynamic capabilities through three activities: sensing, seizing, and transforming. Sensing involves identifying technological and market opportunities, seizing involves mobilizing resources to respond to these opportunities, and transforming involves reconfiguring organizational processes and capabilities.

Accordingly, Dynamic Capabiilities Theory is particularly relevant to digital transformation because organizations must continuously respond to technological developments and changing market and sustainability expectations. Technologies such as automation, AI, data analytics, and connected systems provide opportunities, but firms require appropriate capabilities to effectively implement and utilize them (Teece, 2007; Warner & Wäger, 2019). Therefore, digital transformation involves not only technology adoption but also continuous organizational adaptation.

In this conceptual paper, DIC can be viewed as a dynamic capability that enables firms to convert adopted digital technologies into innovation and transformation. Shen et al. (2022) found that digital dynamic capability mediates the relationship between digital technology adoption and digital transformation performance. Therefore, Dynamic Capabilities Theory helps explain how Digital Technology Adoption can contribute to Green Digital Transformation through the development and application of Digital Innovation Capability.

Resource-Based View

The Resource-Based View (RBV), introduced by Barney (1991), explains that firms can achieve competitive advantage through resources that are valuable, rare, difficult to imitate, and non-substitutable. These resources may include physical, technological, human, organizational, and intangible resources. However, possessing

resources alone is insufficient; firms must also have the skills and capabilities to effectively utilize them (Barney, 1991; Bharadwaj, 2000).

In the context of this conceptual paper, Technology Infrastructure, Digital Integration, Data Analytics Capability and Technology Utilization represent important technological resources and capabilities associated with Digital Technology Adoption. Technology Infrastructure provides the foundation for digital activities, Digital Integration connects systems and processes, Data Analytics Capability enables firms to generate insights, while Technology Utilization allows firms to apply technologies effectively.

Therefore, RBV provides the theoretical basis for DTA by explaining the importance of firms' internal technological resources while DCT explains how these resources can be developed and reconfigured to support innovation and transformation. DIC connects the two perspectives by enabling firms to convert digital resources into innovations that contribute to GDT (Barney, 1991; Teece et al., 1997; Shen et al., 2022).

Development of Research Framework

The research framework consists of three main constructs: Digital Technology Adoption (DTA), Digital Innovation Capability (DIC), and Green Digital Transformation (GDT). DTA comprises four dimensions: Technology Infrastructure, Digital Integration, Data Analytics Capability, and Technology Utilization.

The framework proposes that these DTA dimensions influence DIC, as digital technologies provide the resources and capabilities needed for digital innovation. DIC then influences GDT by enabling firms to transform digital technologies into innovative and sustainable practices. Therefore, DIC is proposed to mediate the relationship between each DTA dimension and GDT, as technology adoption alone may not be sufficient to achieve green transformation.

Development of Propositions

Theoretical rationale for P5–P9. DIC is expected to contribute to GDT (P5) when firms direct digital experimentation and innovation towards energy efficiency, waste reduction, resource traceability, process redesign and other verifiable environmental improvements. However, digital innovation is not automatically green; strategic sustainability priorities and environmental measurement are necessary contextual conditions. P6–P9 posit indirect relationships because each DTA dimension can enable DIC, which can subsequently support environmental transformation. These mediation propositions concern theoretical mechanisms and should not be interpreted as established causal effects. The model does not rule out direct DTA–GDT relationships; future studies should test them to distinguish partial from indirect-only mediation. The expected relationships may differ by firm size, technology maturity, energy intensity, and supply-chain requirements.

Theoretical rationale for P1–P4. Technology Infrastructure (P1) provides computing, sensing and connectivity resources necessary for experimentation, but installed hardware does not itself constitute innovation. Digital Integration (P2) reduces information silos and allows production, quality and supply-chain knowledge to be recombined into new processes. Data Analytics Capability (P3) supports sensing of operational anomalies and opportunities through interpretation of data, although poor data governance may weaken this contribution. Technology Utilization (P4) creates opportunities for experiential learning and iterative improvements through routine use. These mechanisms differ: infrastructure provides access, integration creates cross-functional visibility, analytics produces interpretable insights, and utilisation embeds learning in practice. The propositions therefore represent distinct routes to DIC, rather than four interchangeable measures of technological sophistication.

P1: Technology Infrastructure has a positive influence on Digital Innovation Capability. P2: Digital Integration has a positive influence on Digital Innovation Capability. P3: Data Analytics Capability has a positive influence on Digital Innovation Capability.

P4: Technology Utilization has a positive influence on Digital Innovation Capability. P5: Digital Innovation Capability has a positive influence on Green Digital Transformation. P6: Digital Innovation Capability

mediates the relationship between Technology Infrastructure and Green Digital Transformation.

P7: Digital Innovation Capability mediates the relationship between Digital Integration and Green Digital Transformation. P8: Digital Innovation Capability mediates the relationship between Data Analytics Capability and Green Digital Transformation. P9: Digital Innovation Capability mediates the relationship between Technology Utilization and Green Digital Transformation.

CONCEPTUAL FRAMEWORK AND PROPOSITIONS

Conceptual research approach. This article advances a theory-driven integrative conceptual synthesis rather than a systematic review or an empirical investigation. It brings together the established RBV and DCT mechanisms with studies of manufacturing digitalisation, innovation capability and environmental transformation to derive the nine propositions. No primary data were collected, and no effect sizes, measurement validity statistics or mediation tests are reported. A future systematic review should specify databases, search strings, inclusion and exclusion criteria, screening dates and quality assessment procedures before claiming exhaustive coverage.

The framework developed in this paper is conceptual and is intended for future empirical validation. The proposed relationships are derived from the theoretical arguments and literature reviewed above. Accordingly, the source propositions are reframed as research propositions rather than statistically tested relationships.

DISCUSSION AND IMPLICATIONS

For Malaysian E&E manufacturers, potential applications include digitally enabled monitoring of energy-intensive equipment, traceability of materials, detection of production defects and optimisation of resource use. These are illustrative pathways, not observed findings from this paper. Management should evaluate innovation projects against explicit environmental indicators such as energy use per unit, waste generation, material recovery and emissions intensity. Digital investment also has its own energy and material footprint; consequently, claims of net environmental benefit require appropriate baseline and lifecycle-aware assessment.

The principal conceptual contribution lies in distinguishing digital adoption conditions from the organisational innovation mechanism and the environmental transformation outcome. Prior studies of digitalisation and sustainability may report favourable associations while leaving open whether resource acquisition, organisational use, or innovation conversion explains the outcome. By preserving four differentiated adoption dimensions, the framework offers a more diagnostic account: firms may have adequate infrastructure but fragmented systems, connected systems but limited analytics, or advanced analytics without sustained operational use. These differences imply distinct managerial interventions rather than a generic recommendation to invest in technology.

The proposed framework positions Digital Innovation Capability as the mechanism through which Digital Technology Adoption can support Green Digital Transformation in Malaysian E&E manufacturing. From a Resource-Based View, technology infrastructure, integration, analytics, and utilisation represent strategically relevant digital resources. Dynamic Capabilities Theory extends this logic by explaining how firms can recombine and deploy those resources through innovation capability in response to environmental and technological change. The framework therefore suggests that technology adoption alone is unlikely to generate green transformation unless firms develop the organisational capacity to translate digital resources into new processes, products, and sustainability-oriented practices. For managers, this highlights the importance of aligning digital investment with innovation routines, employee capability development, and explicit environmental objectives.

CONCLUSION AND FUTURE RESEARCH

Future empirical design should recruit firms across E&E subsectors and organisational sizes, with knowledgeable respondents from operations, digital transformation and sustainability functions. Researchers should pilot context-sensitive indicators, assess first-order measurement properties, examine formative

collinearity and weights where a higher-order DTA composite is used, and test indirect effects with bootstrapped confidence intervals. Cross-sectional findings should be reported as associations rather than proof of temporal causation. Longitudinal, multi-informant designs and independent environmental performance data would provide stronger evidence of the proposed mechanism. Studies should also compare alternative model specifications, including direct DTA-to-GDT effects and sustainability-strategy contingencies.

This conceptual paper develops an integrated explanation of how Digital Technology Adoption may contribute to Green Digital Transformation through Digital Innovation Capability. By treating technology adoption as multidimensional and positioning innovation capability as a mediator, the model provides a clearer account of the organisational process connecting digital resources with green outcomes. Future research should validate the propositions in Malaysian E&E manufacturing and may compare firms by size, technological maturity, export orientation, and sustainability intensity. Longitudinal research would also help establish how digital capabilities accumulate and contribute to green transformation over time.

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